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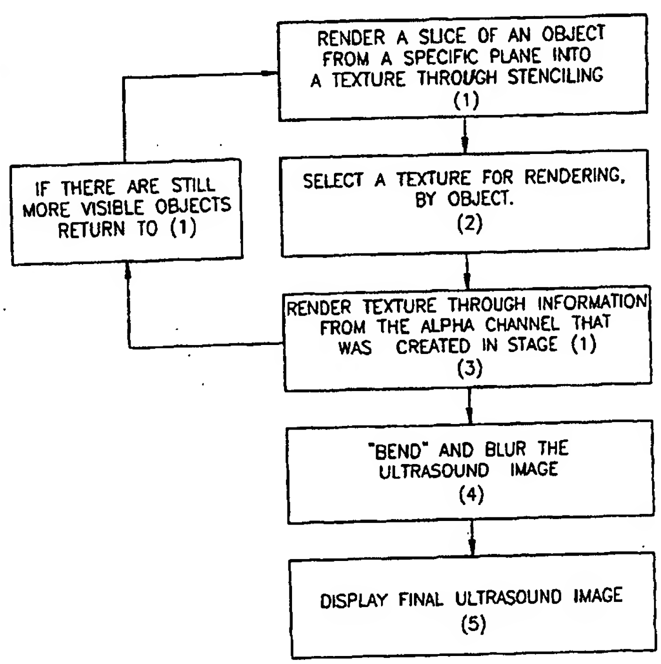
(54) **Title:** ENDOSCOPIC ULTRASONOGRAPHY SIMULATION



(57) Abstract: A method and a system to simulate ultrasound images and hence for simulating the evaluation of a subject with such images as a diagnostic tool. For the purpose of simulating ultrasound images, these images may be considered to be planar slices of a given geometry. These slices are generated from the surface geometry of the portion of the subject which would receive the ultrasound waves if the ultrasound diagnostic procedure was actually be performed. Simulating such ultrasound images may therefore be performed by determining such images from surface models, and then rendering those ultrasound images at the desired position. The rendering of such simulated ultrasound images also optionally and preferably includes the simulation of the "grainy" quality of such images.

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Endoscopic UltraSonography Simulation

FIELD OF THE INVENTION

The present invention is of a method for simulating ultrasound images, and in particular, for such a method for simulating ultrasound images which are produced during a medical diagnostic procedure.

BACKGROUND OF THE INVENTION

ERCP (Endoscopic Retrograde Cholangio Pancreatography) is a minimally invasive procedure which allows the doctor to perform necessary treatments such as enlarging a bile duct opening, removing gallstones lodged in the bile duct, inserting a stent (drain) in the duct or taking a biopsy specimen.

A flexible fiber optic tube, called a duodenoscope, is passed through the mouth, esophagus and stomach into the duodenum, which is the first part of the small intestine. The duodenoscope is a thin, flexible tube with a tiny video camera and light at one side of the tip. The papilla, which is an opening where the bile and pancreatic ducts empty into the duodenum, is visually identified. A small plastic tube, or cannula, is passed through the duodenoscope into the papilla. X-ray dye is injected through the cannula into the ducts. X-rays are then taken to study the ducts. Any necessary treatments can be performed at this time.

This treatment scheme is somewhat similar to gastro-endoscopy, in which an endoscope is inserted through the rectum in order to examine the large colon, for example. In both cases, students are taught to perform such procedures according to the traditional model for medical education, in which students observe and assist more experienced physicians. Unfortunately, such observation alone cannot provide the necessary training for such complicated medical procedures. Students may also perform procedures on animals and human cadavers, neither of which replicates the visual and tactile sensations of a live human patient. Thus, traditional medical training is not adequate for modern technologically complex medical procedures.

In an attempt to provide more realistic medical training for such procedures, simulation devices have been developed which attempt to replicate the tactile sensations and/or visual feedback for these procedures, in order to provide improved medical training without endangering human patients. An example of such a simulation device is disclosed in U.S. Patent No. 5,403,191, in which the disclosed device is a box containing simulated human organs.

Various surgical laparoscopic procedures can be performed on the simulated organs. Visual feedback is provided by a system of mirrors. However, the system of both visual and tactile feedback is primitive in this device, and does not provide a true representation of the visual and tactile sensations which would accompany such surgical procedures in a human patient. Furthermore, the box itself is not a realistic representation of the three-dimensional structure of a human patient. Thus, the disclosed device is lacking in many important aspects and fails to meet the needs of a medical simulation device.

Attempts to provide a more realistic experience from a medical simulation device are disclosed in PCT Patent Application Nos. WO 96/16389 and WO 95/02233. Both of these applications disclose a device for providing a simulation of the surgical procedure of laparoscopy. Both devices include a mannequin in the shape of a human torso, with various points at which simulated surgical instruments are placed. However, the devices are limited in that the positions of the simulated surgical instruments are predetermined, which is not a realistic scenario. Furthermore, the visual feedback is based upon a stream of video images taken from actual surgical procedures. However, such simple rendering of video images would result in inaccurate or unrealistic images as portions of the video data would need to be removed for greater processing speed. Alternatively, the video processing would consume such massive amounts of computational time and resources that the entire system would fail to respond in a realistic time period to the actions of the student. At the very minimum, a dedicated graphics workstation would be required, rather than a personal computer (PC). Thus, neither reference teaches or discloses adequate visual processing for real time visual feedback of the simulated medical procedure.

Similarly, U.S. Patent No. 4,907,973 discloses a device for simulating the medical procedure of flexible gastro-endoscopy. The disclosed device also suffers from the deficiencies of the above-referenced prior art devices, in that the visual feedback system is based upon rendering of video data taken from actual duodenoscopic procedures. As noted previously, displaying such data would either require massive computational resources, or else would simply require too much time for a realistic visual feedback response. Thus, the disclosed device also suffers from the deficiencies of the prior art.

A more useful and efficient medical simulation device for minimally invasive therapeutic procedures such as endoscopy is disclosed in PCT Application No. WO 99/38141, by the present inventors and incorporated by reference as if fully set forth herein. The disclosed medical simulation device provides real time, accurate and realistic visual feedback of general

endoscopic procedures, as well as realistic tactile feedback, so that the visual and tactile systems are accurately linked for the simulation as for an actual medical procedure.

Duodenoscopy of the bilio-pancreatic system would also benefit from such realistic simulation, involving both visual and tactile feedback which are provided in an accurate manner. Bilio-pancreatic duodenoscopic procedures feature many of the same principles as gastro-endoscopy, since for both types of endoscopic procedures, an instrument is inserted into a body orifice, and must then be guided through a tubular organ without direct visual feedback. In addition, the physician performing the procedure must be able to correctly interpret both the indirect visual feedback provided through a video monitor, as well as the tactile feedback through the instrument itself. Therefore, both types of duodenoscopy require the physician to receive "hands-on" manual training for the correct performance of the procedure.

As part of the simulation of this procedure, the students should also be able to practice using the diagnostic tool of ultrasound. Ultrasonography is an optional adjunct to a large number of medical procedures, such as gastro-endoscopy and duodenoscopy. In addition, ultrasonography is itself an important medical procedure, which is used for example in order to safely visualize the fetus during pregnancy. Unfortunately, the background art does not feature suitable methods for accurately and efficiently simulating ultrasound images.

SUMMARY OF THE INVENTION

The background art does not teach or suggest a method and a system to efficiently and realistically simulate ultrasound images. Nor does the background art teach or suggest such a system and method for providing such images as part of the simulation of an overall medical procedure.

The present invention overcomes the deficiencies of the background art by providing a method and a system to simulate ultrasound images and hence for simulating the evaluation of a subject with such images as a diagnostic tool. For the purpose of simulating ultrasound images, these images may be considered to be planar slices of a given geometry. These slices are generated from the surface geometry of the portion of the subject which would receive the ultrasound waves if the ultrasound diagnostic procedure was actually being performed. Simulating such ultrasound images may therefore be performed by determining such images from surface models, and then rendering those ultrasound images at positions given by the tip of the scope. The rendering of such simulated ultrasound images also optionally and preferably includes the simulation of the "grainy" quality of such images.

According to the present invention, there is provided a method for simulating an ultrasound image of at least one anatomical feature of a subject, comprising: determining a surface geometry of the at least one anatomical feature; generating at least one planar slice of the surface geometry according to a location of a simulated source of ultrasound waves; and rendering the ultrasound image according to the at least one planar slice.

Hereinafter, the term "simulated medical procedure" refers to the simulation of the medical procedure as performed through the system and method of the present invention. Hereinafter, the term "actual medical procedure" refers to the performance of the medical procedure on an actual, living human patient with an actual medical instrument, such that the medical procedure is "real" rather than "simulated". Hereinafter, the term "corresponding actual organ" refers to the "real" organ of a human being or other mammal which is being simulated by the simulated organ of the present invention.

Hereinafter, the term "subject" refers to the human or lower mammal upon which the method and system of the present invention are performed or operated. Hereinafter, the term "student" refers to any human using the system of the present invention, being trained according to the present invention or being taught according to the present invention including, but not limited to, students attending medical school or a university, a medical doctor, a trained pancreatic specialist or other trained medical specialist.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, wherein:

FIG. 1 is a flowchart of an exemplary method of the present invention;

FIG. 2 is a flow diagram for determining the output texture for ultrasound images according to the present invention;

FIG. 3 shows exemplary ultrasound texture which is simulated according to the present invention;

FIG. 4 shows labeled exemplary organ slices, visualized through ultrasound, which are simulated according to the present invention; and

FIG. 5 shows an exemplary final ultrasound image, simulated according to the method of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention is related to a method and a system for simulating ultrasound images and hence for simulating the evaluation of a subject with such images as a diagnostic tool. Preferably, but not necessarily, the ultrasound images are simulated as though they had been collected during the evaluation of a subject with gastro-endoscopy and/or duodenoscopy, although of course ultrasound images could optionally be simulated as though they had been collected during substantially any medical procedure.

For the purpose of simulating ultrasound images, these images may be considered to be planar slices of a given geometry. These slices are generated from the surface geometry of the portion of the subject which would receive the ultrasound waves if the ultrasound diagnostic procedure was actually being performed. This surface geometry may optionally be modeled as polygonal models or other surface representation, optionally and more preferably by using common 3D graphic accelerator functionality. Thus, a real-time performance to this simulation may optionally be obtained.

Simulating such ultrasound images may therefore be performed by determining such images from surface models, and then rendering those ultrasound images at positions given by the tip of the scope. Such rendering is similar to that currently performed for modeling regular endoscopy procedures, and is also known as a "movement model". One example of such a movement model is given in PCT Application No. WO 99/38141, filed on January 15, 1999, which is hereby incorporated by reference as if fully set forth herein. This reference also describes an exemplary system for simulating a medical procedure, which could optionally be used with the present invention, for example. Of course, other systems and/or devices could also optionally be used with the method of the present invention.

The present invention differs from such methods of modeling visual data for gastro-endoscopic procedures in that additional areas of the subject, including additional organs and/or organ portions, must also be rendered, since ultrasound waves penetrate beyond the wall of the organ which actually contains the ultrasound probe.

The rendering of such simulated ultrasound images also optionally and preferably includes the simulation of the "grainy" quality of such images. This quality is inherent to the method of ultrasound itself, as it involves sending sound waves to the desired area of the subject and then listening to the echoes, in order to measure the time required for the echo to return. Of course, at least a portion of the actual signal would be attenuated, since not all of the sound waves are reflected by the tissue. The intensity of the echo is also measured to provide the

"echoic property" of the object, in which white spots in an image are hyper-echoic, and black spots are hypo-echoic. The graininess of the image occurs since the sound waves reflect in all directions, so minor echoes that are reflected locations other than the organ being examined also return to the probe, causing static interference with the signal being measured. Such static interference then creates the grainy image.

The principles and operation of a method and a system according to the present invention for the simulation of the medical diagnostic procedure of ultrasound, may be better understood with reference to the drawings and the accompanying description, it being understood that these drawings are given for illustrative purposes only and are not meant to be limiting.

As shown with regard to Figure 1, an exemplary method of the present invention for rendering ultrasound images is described. Although the explanation is given with regard to a simulation of a linear array probe, in which the plane of the scan is parallel to the shaft of the endoscope probe, the system could easily be used to simulate other types of US (ultrasound) scans, for example a radial scan in which the plane of the scan is perpendicular to the shaft of the endoscope. One of ordinary skill in the art could easily alter the simulation process in order to accommodate these differences between scanning devices.

First, a technique called "stenciling" is used to render a slice of an object from a specific plane into a texture (which is basically a bitmap or a digital picture). Stenciling is known in the art of real time graphics, and is also used to simulate shadows and create other real-time computer graphic effects, in conjunction with a stencil buffer. This technique is performed by positioning the viewpoint of a virtual "camera" above the desired plane, in the direction of the plane normal. Positioning of a virtual camera or viewpoint for generating three-dimensional computer graphics is achieved by giving the coordinates of the viewpoint in relation to the coordinates of the object being viewed, by using a standard coordinate system (such as that of the X ,Y & Z Axes for example).

The near Z clip plane is then set to fit the cutting plane. The near Z clip plane is the distance from the camera at which objects begin to be seen, such that objects closer than that distance are clipped or not shown. The requirement for the near Z clip plane in the background art is due to mathematical inaccuracies in computers, as objects cannot to come infinitely close to the camera. However, for the purposes of the present invention, this parameter is preferably set at a specific location in order to cause the object to be cut at a specific plane, in order to be able to render the ultrasound image at that plane. This parameter could optionally be set in any type of three-dimensional (3D) rendering software to cause the object to be so clipped. The

general function of a near Z clipping plane is to remove all the geometry that is closer to the camera than to that plane.

Next, both sides of the surface of the whole object are preferably rendered. All the surfaces of the object are rendered, even those which are not seen such as those which are removed from view, for example in the event that a near Z clipping plane has been applied. When the object is rendered, the stencil buffer associated with that software is preferably used to count the amount of pixels written to the buffer. If an even amount of pixels are written, the slice is not visible, and if an odd number of pixels are written, the slice is visible, as shown with regard to Figure 2. This effect occurs because both sides are rendered, but with different parameters. For those portions of the object which should not be displayed (such as the back part of an object, which could not be seen from the perspective of the user), each time a pixel is written to the image buffer, the stencil value for this pixel is incremented. For those portions which should be displayed, the value in the stencil buffer is decreased by one. The stencil buffer is therefore a bitmap of 0 and 1 values, in which values of "1" indicate where this object intersects the ultrasound image plane.

A texture is then preferably selected which resembles the texture of the ultrasound image for the desired object, which could optionally be extracted from real ultrasound images of the organ or other tissue, such as images of the liver for example. Next, this texture is rendered by using the previously defined information from each slice as the alpha channel. The alpha channel is another color channel which is added frequently in 3D graphics and computer graphics generally, in addition to the common Red/Green/Blue channels (or color components). The alpha channel is related to the amount of transparency of the color. The data of the fourth channel is then preferably applied to all graphic components containing color. With regard to Figures 2 and 3, the alpha channel is used to determine which areas of the simulated images below are transparent.

With regard to the texture, in order to add visual realism to those portions of image in the previously described stencil buffer, texture is preferably added to those portions of the image having values of "1" in that buffer. For the purposes of this description, the texture is preferably added in grayscale, although of course colors could optionally be added.

These steps are preferably performed for each object separately until all visible object slices are rendered, resulting in a simulated image as shown below with regard to Figure 4. The image is then preferably "bent" and blurred to simulate the poor resolution of true ultrasound images. The process of "bending" the image is more preferably performed mathematically, while

blurring may optionally and more preferably be performed through image processing which also involves a mathematical function, and which is also very well known in the art.

All the work done previously is rendered to a surface that is not visible to the user, such that there is now a rectangular picture that represents slices of all the objects that intersected the US plane. If it is taken into consideration that the US probe is not straight, but is in fact an array of sensors in the shape of an an arc, the resulting image should be in the shape of a sector circumscribed by an arc parallel to the base arc of the sector. To obtain this image the rectangular picture is rendered onto a template in the shape of a sector as described above, in which the template is a polygonal model that describes the ultimate overall shape of the image. The result of these processes is shown in the exemplary image of Figure 5.

After these processes have been performed, the relevant anatomy has been modeled onto surface models of the anatomical feature, such as the organ. Each object has been rendered with the associated ultrasound properties, such as how the tissue responds to ultrasound waves in terms of echoing, and with a sample of the correct filling texture for simulation of the ultrasound image. For example, since moving the endoscope or other tool which holds the probe also alters the probe's position, the position of the cutting plane may be altered with each movement. In turn, the slices generated by the cutting plane are changed, such that a new ultrasound image is formed. The final simulated ultrasound image is then displayed to the user (see Figure 5 for an example).

As previously described, one of ordinary skill in the art could easily adjust the method of the present invention in order to accommodate different types of ultrasound scanning technologies. For example, for a radial scanning the device, the image would only have "blur" added, but would not be "bent", because the plane of scanning is perpendicular to the device. Also, the image would be round rather than square.

It will be appreciated that the above descriptions are intended only to serve as examples, and that many other embodiments are possible within the spirit and the scope of the present invention.

WHAT IS CLAIMED IS:

1. A method for simulating an ultrasound image of at least one anatomical feature of a subject, comprising:

determining a surface geometry of the at least one anatomical feature;

generating at least one planar slice of said surface geometry according to a location of a simulated source of ultrasound waves; and

rendering the ultrasound image according to said at least one planar slice.

2. The method of claim 1, wherein said generating said at least one planar slice is performed by using a stencil buffer.

3. The method of claim 2, wherein said generating with said stencil buffer is performed by:

positioning a viewpoint for collecting the ultrasound image above said at least one planar slice; and

setting a near Z clip plane to fit a cutting plane for cutting said at least one planar slice.

4. The method of claim 3, wherein said generating with said stencil buffer is further performed by:

setting a value for pixels for said planar slice to a positive value, and a value of pixels for the remainder of the anatomical feature to a zero value; and

rendering said pixels.

5. The method of claim 3, wherein said generating with said stencil buffer is further performed by:

determining at least one intersection of the anatomical feature with said planar slice; and

setting a value for said pixels in said planar slice to a positive value for said stencil buffer.

6. The method of any of claims 1-5, wherein the ultrasound image is a grayscale image and wherein said rendering further comprises rendering said grayscale image with a selected texture, said selected texture being collected from an actual ultrasound medical procedure.

7. The method of any of claims 1-5, wherein the ultrasound image is a black and white image, and wherein said rendering further comprises rendering said black and white image with a selected texture, said selected texture being collected from an actual ultrasound medical procedure.

8. The method of either of claims 6 or 7, wherein said rendering with said selected texture is only performed for pixels in said stencil buffer having a positive value.

9. The method of claim 8, wherein said pixels having said positive value are white pixels.

10. The method of claims 6 or 7, wherein a simulated ultrasound image is created by rendering said texture on said at least one planar slice.

11. The method of claim 10, wherein rendering said texture further comprises at least one of bending and blurring said simulated image.

12. The method of claim 11, wherein said bending further comprises:

rendering said simulated image onto a template, said template comprising a polygonal model constructed according to a shape of an image from an actual ultrasound medical procedure .

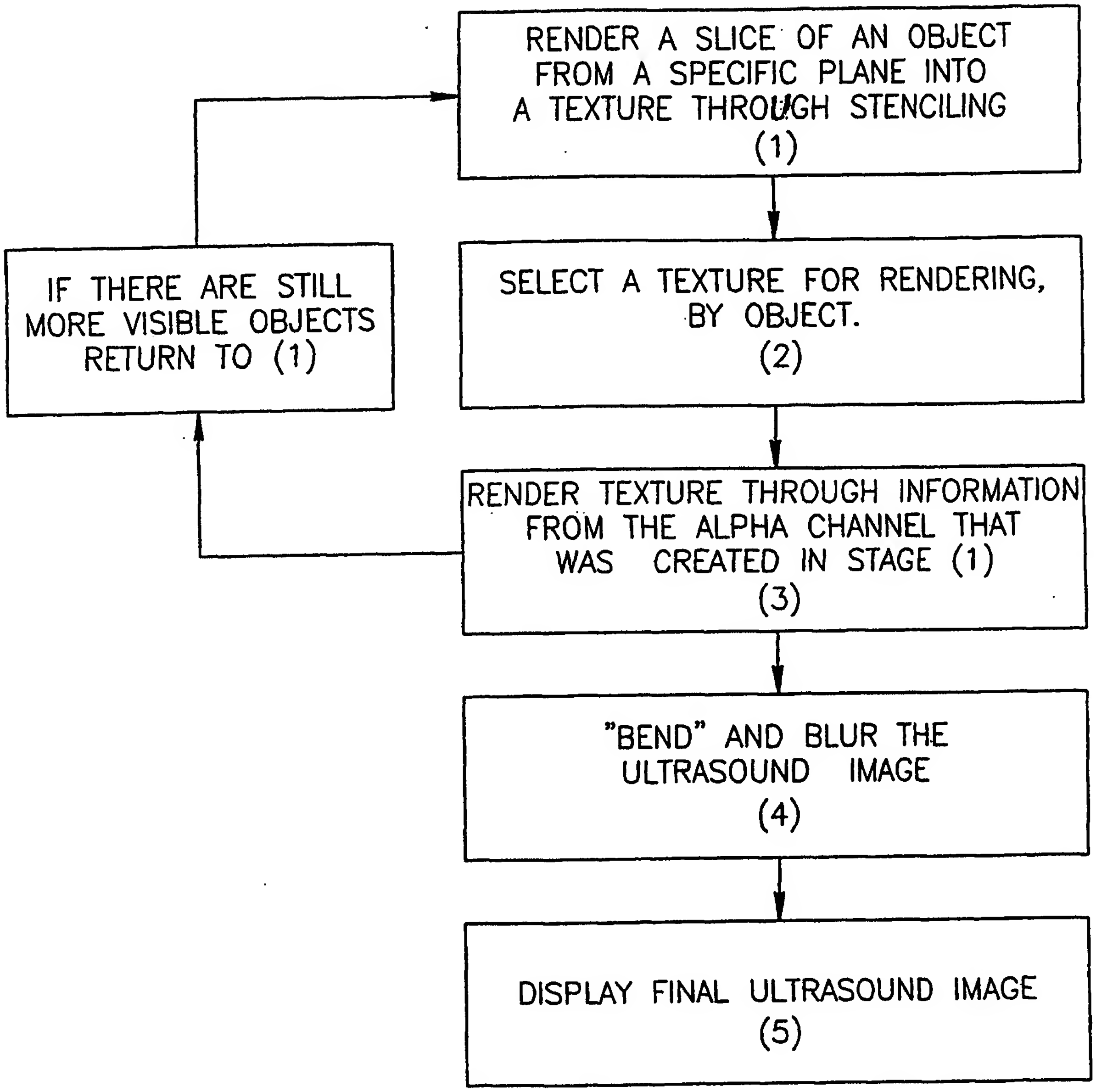
RENDER A SLICE OF AN OBJECT FROM A SPECIFIC PLANE INTO A TEXTURE THROUGH STENCILING (1)
SELECT A TEXTURE FOR RENDERING, BY OBJECT. (2)
RENDER TEXTURE THROUGH INFORMATION FROM THE ALPHA CHANNEL THAT WAS CREATED IN STAGE (1) (3)
"BEND" AND BLUR THE ULTRASOUND IMAGE (4)
DISPLAY FINAL ULTRASOUND IMAGE (5)
IF THERE ARE STILL MORE VISIBLE OBJECTS RETURN TO (1)

FIG.1

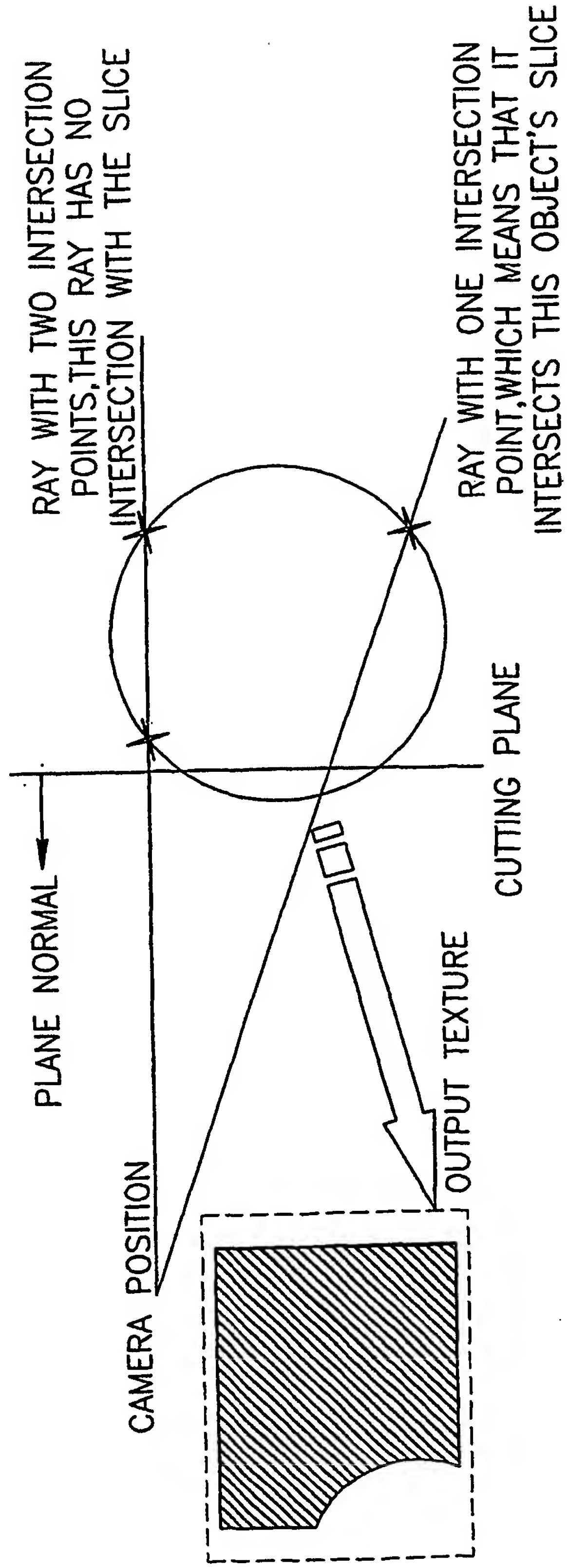
RAY WITH TWO INTERSECTION POINTS,THIS RAY HAS NO INTERSECTION WITH THE SLICE
RAY WITH ONE INTERSECTION POINT,WHICH MEANS THAT IT INTERSECTS THIS OBJECT'S SLICE
CUTTING PLANE
PLANE NORMAL
OUTPUT TEXTURE
CAMERA POSITION

FIG.2

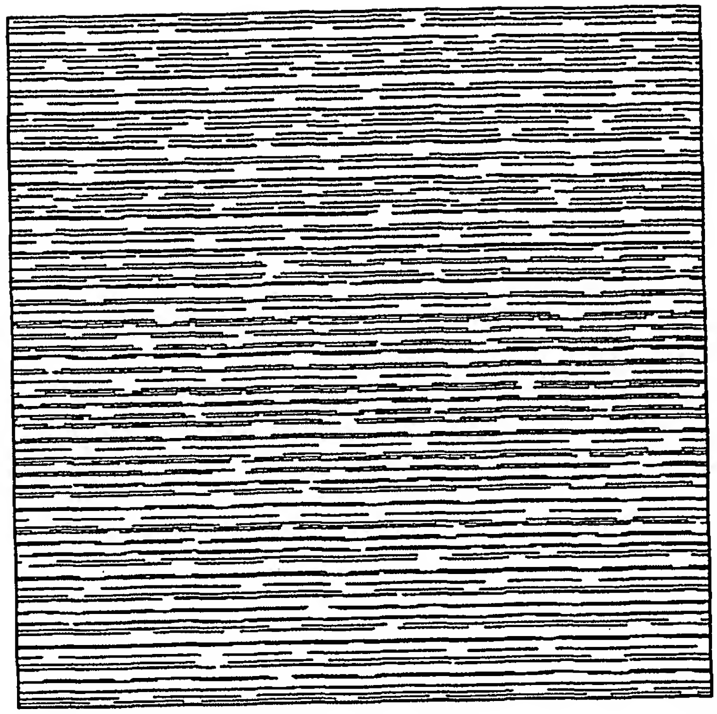

FIG.3

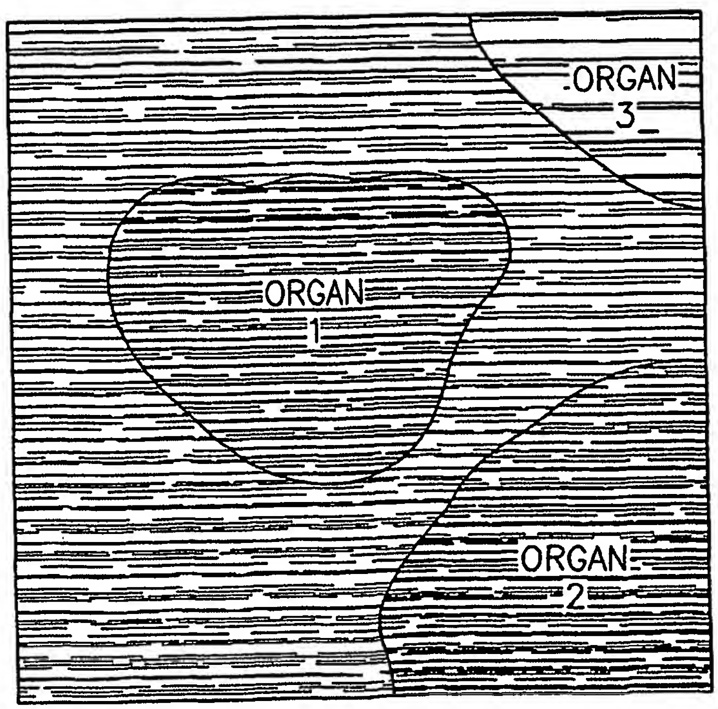

FIG.4

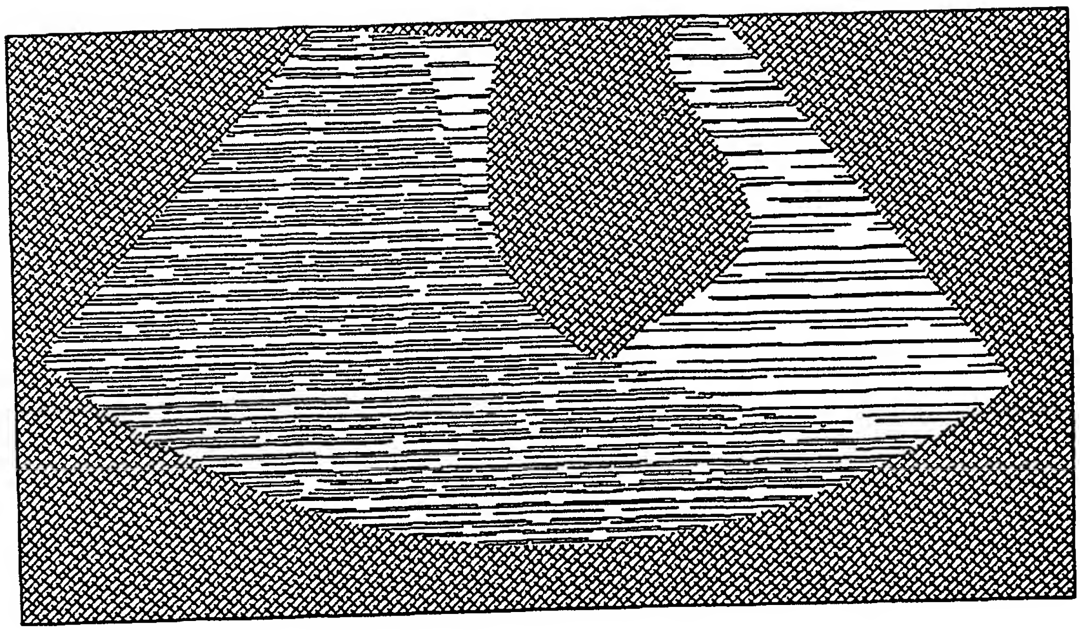

FIG.5